KAY SPFD

UNITED STATES GOVERNMENT

memorandum

DATE: February 6, 1987

REPLY TO ATTN OF: Field Supervisor, CMFO

SUBJECT: White Paper, "Impact of Lead on Migratory Birds in Missouri"

TO: Regional Director, AE/EC

Big River Min
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Attached for your use is the final of the White Paper, "Impact of Lead on Migratory Birds in Missouri". Your comments on the draft were both appreciated and incorporated in the final.

Joe Tieger

Impact of Lead on Migratory Birds in Missouri

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ABSTRACT

The Old Lead Belt of Southeastern Missouri (St. Francois and Madison Counties) contains 227 million kilograms of abandoned lead mine tailings. With the rupture of a major tailings dam in 1977, and the continual erosion and seepage of the tailings, the lead has and continues to contaminate the Big River by being deposited in the sediments. In turn, fish, birds, and wildlife have been acquiring the lead by direct ingestion of the sediment, by obtaining the leached lead within the water, or by consumption of lead contaminated food.

BACKGROUND

Fifty-six percent, or 760 million kilograms (838 thousand tons), of the lead used annually in the United States enters the environment (Nriagu 1978), from sources such as automobile emissions, mining activities, factory operations, and lead shot. As the lead enters the environment and becomes available to fish and wildlife, lead poisoning becomes a problem. Lead poisoning affects the nervous system, the transfer of oxygen to the tissues, and the production of hemoglobin, resulting in anemia. The liver and the kidney are the best indicators of acute lead poisoning, while the bones indicate chronic exposure (Adler 1944; Chupp and Dalke 1964). Approximately ninety percent of the lead is eventually deposited in the skeleton (Kendall and Scanlon 1982). Sick avians can be characterized by listlessness, emaciation, and green-stained matted feathers on their vent. Impacted food in the gizzard is common, but starvation continues until death (Rosen and Bankowski 1960).

MISSOURI LEAD MINING

Missouri has been the number one producer of lead in the United States since the 1920's (Wixson 1977). Ore deposits of Galena were discovered in southeast Missouri in the early 1700's in what is known as "The Old Lead Belt" (see map A). In 1848, mines were opened in the southwestern portion of Missouri, near Joplin in what is known as "The Tri-State Mining District". Then in 1955, after the ore deposits in the Old Lead Belt were depleted, "The New Lead Belt", or "Viburnum Trend", became the world's largest lead producing district, with production starting in 1955. By 1970, 74.4% of the entire U.S. lead mine production came from this area (Gale et al. 1973).

Both the New Lead Belt and the Tri-State area do not pose an immediate threat to the environment. According to Czarnezki (1985), lead concentrations in fish from streams adjacent to the mining areas were not significantly different from the control areas. Although these mining operations adversely affect Missouri streams to a certain extent, they have an efficient milling process in removing the lead from the ore and do not represent an immediate concern.

The major problem is the Old Lead Belt, which lies in St. Francois and Madison Counties, 113 km (71 miles) south of St. Louis, Missouri. The area covered consists of 285 sq. km (111 sq. miles), bordered by latitudes 38° 00' and 37° 49' 45" (Elliott 1982). Between 1864 and 1972, the mines from the Old Lead Belt generated 227 million kilograms (250 thousand tons) of tailings, with some individual tailings piles covering an area of 648 hectares (1,600 acres). A tailing is the residue that remains after the lead and other metals have been extracted from the ore. Erosion and seepage of lead from these tailings into the Big River in the Old Lead Belt pose a constant threat to the aquatic biota. The Big River is the fourth largest free-flowing stream in the Missouri Ozarks, originating in Iron County and flowing northeast through the Old Lead Belt and entering the Meramac River near Eureka (see map B). Its 240 km (150 mile) length is impacted for at least 60 km (38 miles) by lead mine tailings, covering approximately 1,215 hectares (3,000 acres) and containing up to 26,600 ppm dry weight of lead (Whelan 1983). With the rupture of a major tailings dam at Desloge, Missouri in 1977, 38,230 cubic meters (50,000 cubic yards) of tailings were washed into the Big River (Novak and Hasselwander 1980). According to Schmitt and Finger (1982), the lead deposition extended 96 km (60 miles) downstream from the rupture at Desloge. Lead is biologically available and biochemically active in the Big River ecosystem (Schmitt et al. 1984).

Most lead salts are insoluble in water; therefore, it becomes deposited within the sediment. In the Great Lakes, the sediments are the dominant sinks for lead. For example, in Lake Erie 75 percent of the lead deposited into the lake is retained in the sediments (Great Lakes Science Advisory Board). Perhae (1972) postulates that 90 to 99 percent of all lead is in the sediment complexes. Because the Big River is well buffered, free lead ions are at low concentrations in the water. However, suspended particles do remain in the streams and affect the water quality of the stream and the aquatic life forms (Gale et al. 1973).

Sediment concentrations of lead tends to be greatest in areas where water is deep and slow moving, and least in shallow or nearshore waters where water movements restrict the build-up of lead (Great Lakes Science Advisory Board). Within a lake, the average lead value for deep layers of an unpolluted lake sediment is 16 ppm and for the surface layers, 95 ppm (Nriagu 1978). At Clearwater Lake in Missouri, which is the recipient of most of the surface waters that drain the New Lead Belt, the lead concentration in the sediment ranges from 3 ppm to greater than 60 ppm. It was concluded that the lead concentrations were well within the limits of tolerance. However, the lake frequently floods, which is a contributing factor to the tolerant lead levels, because the increased flows have a diluting effect on the concentrations (Gale et al. 1976). In Lake Coeur d'Alene in Idaho, greater than 5,000 ppm have been estimated within the sediments. This ecosystem is being affected due to the deposition of mine wastes, which have caused extensive waterfowl mortality (Chupp and Dalke 1964). Typically, the sediments in a polluted river have been found to have an average lead value of 98 ppm (Nriagu 1978). Although the lead is accumulated within the sediments, some leaching into the water occurs. Values as high as 2,900 ppm for sediments have been reported for the Big River (Schmitt and Finger 1982).

BIOLOGICAL EFFECTS

Fish and wildlife acquire the lead either by direct ingestion of the sediment, by obtaining the leached lead within the water, or by consumption of lead contaminated food. In several studies on lead in Great Lakes fish (Leland and McNurney 1974; Whittle 1980; Great Lakes Science Advisory Board), the smaller planktivores and omnivores with a high surface-to-body weight ratio had higher lead concentrations, which presumably allows for easier adsorption. Benthic (bottom) feeders are the primary organisms at risk. Herbivorous fish tend to develop higher concentrations of lead than carnivorous fish, perhaps due to a smaller size, diet composition, or feeding by sifting contaminated sediments (Leland and McNurney 1974). Because of the diet of herbivorous fish, they have a more direct link in obtaining lead (Great Lakes Science Advisory Board). In studying the concentration of lead in the Big River, Czarnezki (1985) found that suckers (Moxostoma spp., Hypentelium spp.), which are benthic feeders, had much higher levels of lead than the smallmouth bass (Micropterus dolomieui), which spends little time foraging on the stream bottom. The amount of lead in the suckers in 1980 posed such a hazard that the Missouri Division of Health, in conjunction with the Missouri Department of Conservation, recommended that suckers caught within 64 km (40 miles) downstream of the break in the Desloge tailings dam on Big River, not be eaten (Czarnezki 1985). Also, it should be noted that Czarnezki's study reflected lead levels from fillet samples, but lead concentrations in whole fish are much higher (Schmitt 1986), which is important because fish-eating wildlife consume the entire fish.

Not only are benthic fish acquiring lead through the lead-contaminated sediment, but those birds that sift the bottom of lakes and rivers in search of food are at risk as well. Most of the literature reviewed on birds that obtain lead by sifting, deal with the ingestion of lead shot; yet there is no reason to believe that lead from contaminated sediments would not be acquired by these birds in the same way. At Tule Lake in California, tundra swans (Cygnus columbianus) were believed to have acquired lead shot from the bottom of lakes and ponds enroute to their northern migration. Mortality losses of tundra swans were attributed to lead poisoning (Rosen and Bankowski 1960). Similarly, trumpeter swans (Cygnus buccinator) died of lead poisoning in western Canada as they fed, acquiring sand from lead contaminated sediment (Munro 1925). According to the Missouri's Fish and Wildlife Information System (Koeln and Urich 1984), many diving ducks inhabit the Big River including the ring-necked duck (Aythya collaris), common goldeneye (Bucephala clangula), redhead (Aythya americana), greater scaup (Aythya marila), and lesser scaup (Aythya affinis). These birds are probably at risk of acquiring lead from contaminated sediment as they search for food. The dabbling ducks such as the

American black duck (Anas rubripes), mallard (Anas platyrhynchos), American wigeon (Anas americana), and northern shoveler (Anas clypeata) also acquire lead by ingesting sediment in the process of feeding (Reid 1948; Trainer and Hunt 1965).

Another factor to consider is that some lead is leached into the water from the sediment. The suspended particulate matter containing lead has been shown to adsorb (adhere to the surface) to crayfish (Orconectes nais) and the foliage of macrophytes. Lead is also absorbed through the roots of these plants, but there is little vertical transport from the roots to the foliage; therefore, the lead that occurs on the foliage results from the desorption of lead ions into the water from the sediment and the subsequent adsorption onto the plant surface (Behan et al. 1979; Knowlton et al. 1982). Similarly, the leached lead adheres to the exoskeleton of the crayfish. Crayfish usually eat their old exoskeleton soon after molting; therefore, they ingest high concentrations of lead in their systems. While molting lessens the external concentration of lead, it increases the internal level. Crayfish feed primarily on worms, insects, and fish, and may acquire lead from these organisms. Lead that is absorbed directly through the gills has been shown to affect the respiration of the crayfish (Knowlton et al. 1982). The observation that crayfish and macrophytes obtained lead through adsorption of the lead from the sediment leaves open the possibility of other organisms contacting lead in this way as well. The suspended particles, containing lead, adhering to the surface of organisms and vegetation is therefore a threat to both predators and herbivores.

In all probability the greatest route of exposure is from ingestion of lead contaminated food. According to Niethammer et al. (1985), lead concentrations decrease with increasing trophic levels. The bottom feeding animals such as the crayfish, fish, and waterfowl that directly ingest the lead are at risk of contamination. Also, it remains a threat to those organisms that continually consume lead contaminated food. For example in southeastern Pennsylvania, muskrats (Ondatra zibethicus) were found to have high lead levels because they fed on cattails that had been exposed to lead (Erickson and Lindzey 1983).

Muskrats in Niethammer's study (1985) showed higher lead levels in the contaminated Big River ecosystem when compared to controls. Muskrats are chiefly vegetarian, but it has been found that muskrats in the Missouri Ozarks also feed on crayfish, fish, frogs, and reptiles (Schwartz and Schwartz 1981). Bullfrogs, water snakes, and crayfish, all from the Big River, have been reported to have high lead levels (Niethammer 1985). Although most consumers of crayfish do not digest the exoskeleton, the fact that the lead is merely adsorbed to the exoskeleton may allow for the lead to be absorbed (Knowlton et al. 1982).

Green-backed herons (Butorides striatus) were also shown to have high lead concentrations in Niethammer's study (1985) on the Big River (0.15 ppm to 1.47 ppm). These lead levels were nearly six times greater than the lead levels in green-backed herons from an uncontaminated river. Herons and their allies are wading birds that feed on aquatic animal life in shallow water. Besides the green-backed heron, the Big River is habitat for the great blue heron (Ardea herodias), cattle egret (Bulbulcus ibis), great egret (Casmerodius albus), the snowy egret (Egretta thula), little blue heron (Egretta caerulea), and the American bittern (Botaurus lentiginosus) (Koeln and Urich 1984). The common loon (Podiceps auritus) also feeds on various invertebrates and risks contamination. The green-backed heron consumes crayfish, especially herons that live in riverine habitats, but fish constitute the main part of their diet.

Although there is little literature on other lead contaminated fish-eating birds, it is reasonable to assume that other species of birds are being affected by eating the lead contaminated fish. Other birds inhabiting the Big River include the belted kingfisher (Ceryle alcyon), hooded merganser (Lophodytes cucullatus), bald eagle (Haliaeetus leucocephalus), double-crested cormorant (Phalacrocorax auritus), and osprey (Pandion haliaetus), all primarily feeding on fish (Koeln and Urich 1984). These birds may also be contaminated.

According to Stendell (1980), bald eagles do not regurgitate castings regularly; thus, they retain the lead. The bald eagle is able to accumulate lead up to a certain point, but at this "threshold point" any additional lead contamination will result in cessation of eating and ultimately death (Pattee et al. 1981). According to Pattee et al. (1981), lead levels greater than 10 ppm in the liver of bald eagles and greater than 5 ppm in the kidney of bald eagles, are good indicators of acute exposure to lead. In waterfowl, the critical lead intake level is estimated to be between 6 and 8 ppm before death occurs (Coburn et al. 1951). Lead was confirmed to interfere with normal sexual development in Japanese quail (Morgan et al. 1975) and affected the fertility of mallards (Elder 1954).

In northern Idaho, lead that had accumulated on the vegetation due to mine wastes affected many birds that fed on these plants (Chupp and Dalke 1964). The birds that showed high levels of lead included the American coot (Fulica americana), wood duck (Aix sponsa), snow goose (Chen caerulescens), northern pintail (Anas acuta), and Canada goose (Branta canadensis). It was found that birds that were feeding on the dead, lead-contaminated waterfowl, were being affected in turn; these included the bald eagle, red-tailed hawk (Buteo jamaicensis), American crow (Corvus brachyrhynchos), herring gull (Larus argentatus), and ring-billed gull (Larus delawarensis). All of these birds occur in the Big River area.

Many animals and birds effected by lead die but are not found. Pheasants (Phasianus colchicus), quail (Callipepla spp.), and other gallinaceous birds are rarely found due to dense habitat, rapid decomposition, and scavenging animals (Westemeier 1966). Also, many birds may migrate from the area where they ingest lead, dying at different locations.

Young birds are affected at lower concentrations than adults due to their developing nervous system. In one-day old American kestrels (<u>Falco sparverius</u>), it was found that greater than 2 ppm lead in the liver or greater than 6 ppm lead in the kidney may be associated with growth impairment and greater than 5 ppm in the liver, 15 ppm in the kidney, or 2 ppm in the brain may be associated with impaired survival (Hoffman 1985). It is important to remember that lead accumulation in the soft tissues is greatest in the kidney and liver, yet the bones rapidly incorporate the lead and retain it for long periods of time. Therefore, over time, the build up of lead in the bones may have serious effects (Stendall 1980).

In addition to eating the lead-contaminated vegetation, animals may acquire lead through ingestion of the water which contains lead. Algal blooms, which are common in tailings ponds and streams near milling operations, trap particles of lead from the water. As the algae die or turbulent conditions arise, these trapped particles are transported downstream (Gale et al. 1976). It was also found by Niethammer et al. (1985), that bank swallows (<u>Riparia riparia</u>) show higher incidences of lead (2.0 ppm to 39 ppm) than rough-winged swallows (<u>Stelgidopteryx serripennis</u>) of the Big River area presumably because the bank swallows nest in the tailings. The rough-winged swallows nest in natural rock ledges. The bank swallows obtain the lead through adsorption, respiratory exposure, and direct ingestion from preening metal dust-laden feathers (Niethammer et al. 1985).

LEAD TRANSPORT THROUGH THE AIR

Also of concern in lead exposure is aerial transport of lead and subsequent deposition on vegetation, where it becomes accessible to wildlife. Aerial transport needs to be looked at closely. Lead is emitted into the air by smelters, through wind erosion from tailings, and through automobile emissions.

Lead smelters are one source of lead contaminated particulate matter (Wixson 1977), although not the major source. The major sources appear to be non-point sources, such as trucking or railroad operations (Wixson 1977). Automobiles are also responsible for large amounts of lead being emitted into the environment. Of the sixty percent of lead used in the auto industry, twenty percent is used in the production of tetraethyl lead for gasoline with seventy to eighty percent of that twenty percent being released into the environment. Although the trend has been to non-leaded gasoline, there has been a 50-year period in which lead has been used in gasoline. Roadside soil 1.5 meters (1.6 yards) away from a highway in Minnesota contained 245 ppm of lead, as compared to 75 ppm, 61 meters away (67 yards) (Alexander 1972). Lead is strongly adsorbed by soil and thus is a problem near roadsides. Plants that grow in this soil absorb the lead through their roots and there is some vertical transport; therefore, it may pose a problem for wildlife that feed on these plants. It takes a large amount of lead concentration to pose a serious threat, but in combination with other metals, the effect is greater (Hassett et al. 1976). Lead uptake by plants is generally a function of the amount of lead in the soil.

Birds, most notably ground insectivores, are prone to accumulation of lead contamination from lead contaminated soil. In Virginia, rock doves (Columba livia) were shown to have acquired lead because they ingested grit from the roadside. Although the levels were not extremely high, the possibility of chronically lethal exposure remains (Kendall and Scanlon 1982a). Furthermore, urban birds were shown to have higher lead concentrations (12 ppm) than rural birds (2 ppm) but showed no apparent adverse effects from it (Kendall and Scanlon 1982b). In Maryland, highway birds were also shown to have a higher lead intake than rural birds, but again showed no signs of intoxication. Grue et al. (1984) state that ground feeding birds are subjected to higher concentrations of lead than aerial feeding birds.

CORRECTIVE MEASURES

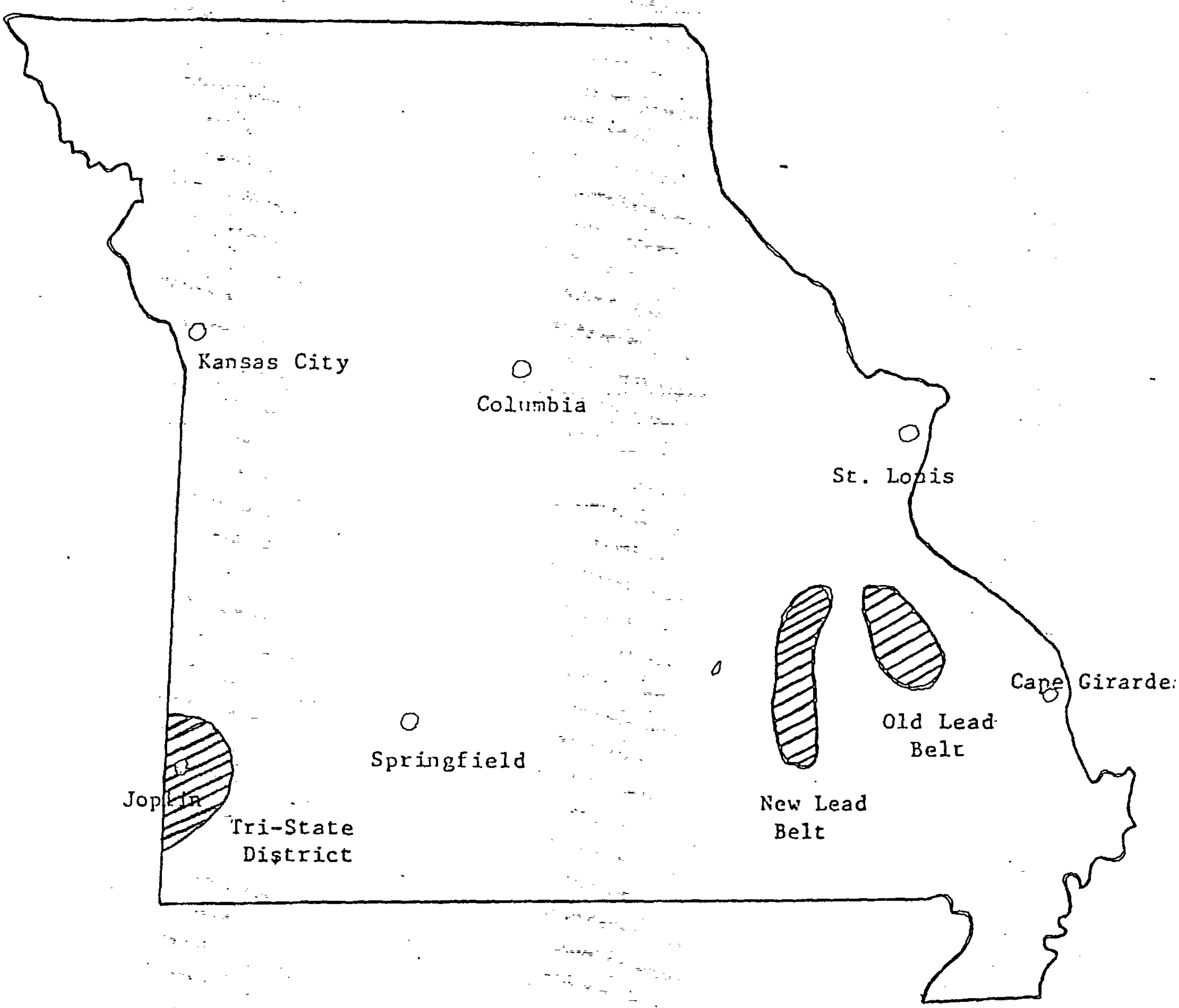
After the rupture of the dam at Desloge in 1977, many agencies were involved in trying to deal with the problem. Concern was expressed, numerous recommendations and proposals were made, but groups such as the University of Missouri at Rolla, Department of Civil Engineering and the Missouri Department of Natural Resources, Missouri Geological Survey that had seriously planned on reconstructing the dam were unable to obtain the appropriate funds (George 1983).

Of the numerous recommendations that have been proposed in the past, the most popular one has been to vegetate the tailings. It has been found that the tailings will support a vegetative cover if fertilized and planted in grass, thus lessening wind and water erosion (George 1983; Schmitt 1985).

Two proposals included: 1) returning the tailings to the underground cavities from which they were taken and 2) chemically stabilizing the tailings so that a crust is formed (George 1983).

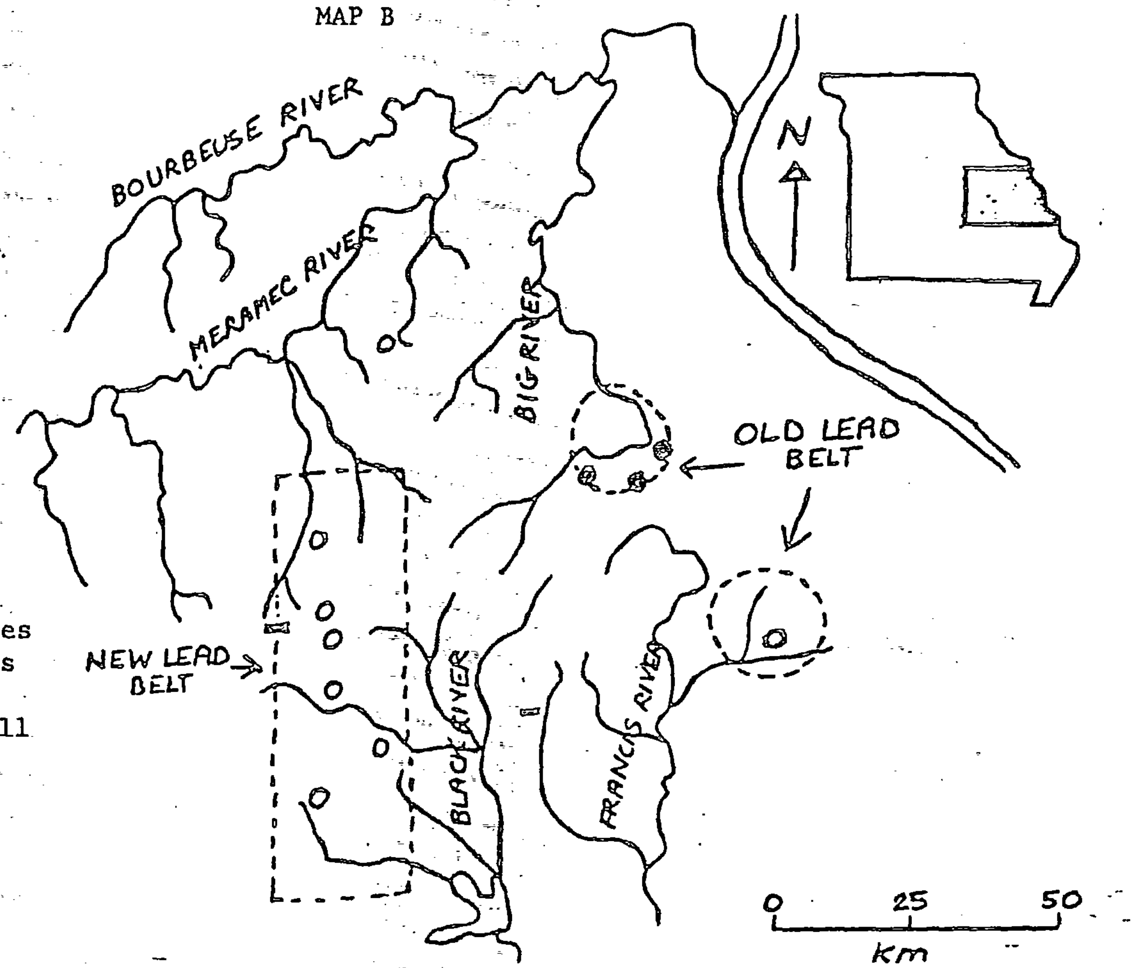
The Bureau of Mines, along with the St. Joe Mineral Company, had a project underway for vegetative stabilization, but the project was canceled as of July 1983, for unknown reasons (George 1983). In 1980, the Missouri Department of Natural Resources estimated that it would cost $200,000 to control mine tailing discharges into the Big River from a 200 hectare (500 acres) tailing site (Novak and Hasselwander 1980). It is estimated that the Big River drainage alone contains 1,215 hectares (3,000 acres) of tailings.

MAP A



Kansas City
Columbia
St. Louis
Cape Girarde
Old Lead Belt
Springfield
New Lead Belt
Joplin
Tri-State District

MAP B

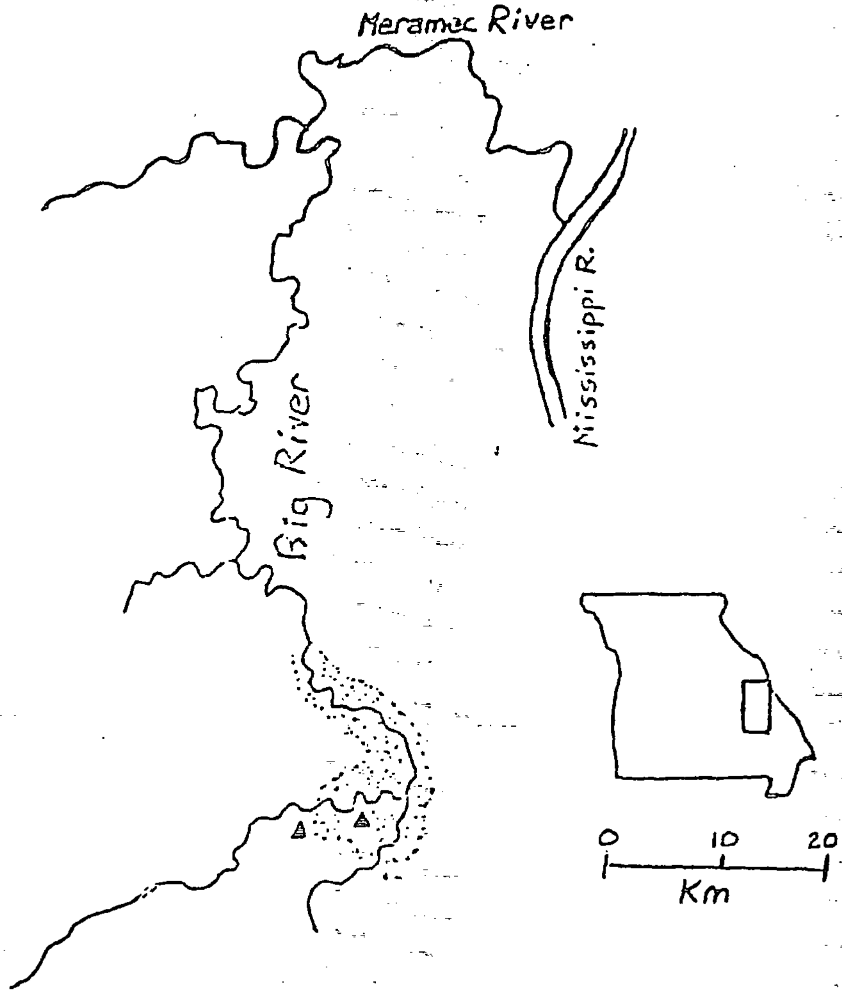


Abandoned lead mines and settling basins

Active mine and mill facilities

Active smelters

(Taken from J.M. Czarnezki 1985 Accumulation of lead in fish from Missouri streams impacted by lead mining)



Major source of mine tailings to Big River

Sediments that are composed of tailings

(Taken from C.J. Schmitt et al. 1984 Bioavailability of lead and zinc from mine tailings as indicated by erythrocyte δ-aminolevulinic acid dehydratase activity)

APPENDIX

Rare and Endangered Bird Species of Missouri's Big River

E = endangered-Official Federal or State classification
R = rare-Official State classification

Scientific name	Common name	Status U.S.	Status MO.
Accipitridae			
Accipiter cooperii	Cooper's hawk		E
Accipiter striatus	sharp-shinned hawk		E
Buteo lineatus	red-shouldered hawk		R
Circus cyaneus	northern harrier		E
Ictinia mississippiensis	Mississippi kite		R
Haliaeetus leucocephalus	bald eagle	E	E
Pandion haliaetus	osprey		E
Ardeidae			
Botaurus lentiginosus	American bittern		R
Egretta caerulea	little blue heron		R
Egretta thula	snowy egret		E
Falconidae			
Falco peregrinus	peregrine falcon	E	E
Phalacrocoracidae			
Phalacrocorax auritus	double-crested cormorant		E

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In studies on 6 birds, the liver proved best for analysis and the bones for determining chronic poisoning. Included were 2 captives showing no current lesions but revealed prior exposure to lead-poisoning upon analysis. Pb varied from 0 to 192 ppm in different organs and specimens. — T.I. Storer.

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Several samples of soil were taken at various locations around the state of Illinois from 1925 until 1972 to determine the lead content. In 1925, the overall average was 10 ppm and recent values were 25 ppm. It was determined that the lead content was highest in the surface soils of the northeast to southwest corridor of Illinois due to the heavy volume of traffic. — D.M. Kania.

Baumhardt, G.R. and L.F. Welch. 1972. Lead uptake and corn growth with soil-applied leads. J. Environ. Qual. 1:92-94.

Corn (*Zea mays* L.) was grown in the field where lead acetate had been soil-applied at 8 rates ranging from 0 to 3,200 kg/ha of lead. Emergence, plant height, and grain yield were not affected by added lead. Neither were any morphological, color, maturity, or other growth differences visually observed during the 2-year study. Added lead increased the lead content of stover. Lead content (ppm) of the stover for the 0 and 3,200 kg/ha treatments were: 2.4 and 37.8 for young whole plants, 3.6 and 27.6 for leaves at tasselling, and 4.2 and 20.4 for whole plants at grain harvest. Lead content of grain averaged 0.4 ppm lead and was not affected by added lead. — Authors' Abstract.

Besser, J.M. 1985. Bioavailability and toxicity of heavy metals in mine tailings leachate to aquatic invertebrates. M.S. Thesis, Univ. Mo.-Columbia.

Erosion and leaching of large deposits of lead mine tailings in the "Old Lead Belt" of southeast Missouri have led to extensive contamination of streams of the Big River drainage with toxic heavy metals. Although revegetation of the tailings piles to reduce erosion has been proposed, the effects of revegetation on the release of metals from the tailings have not been studied. In this study, aquatic invertebrates were exposed to leachates from test plots of tailings to evaluate the effects of cover materials on the bioavailability and toxicity of metals in tailings leachates.

Bioaccumulation of metals from test plot leachates was increased in tailings plots with cover treatments of vegetation (seed/fertilizer and sod treatments) or organic matter (sludge and leaf treatments), relative to uncovered tailings or uncontaminated crushed dolomite. Differences in metal bioaccumulation among treatments corresponded to dissolved metal concentrations in leachates, although invertebrates were apparently able to accumulate metals from ingested solids as well. Formation of complexes with dissolved organic compounds led to high metal concentrations in leachate from the leaf treatment, which showed the highest metal bioaccumulation.

Toxic effects of leachates on survivorship of crayfish and survivorship, growth, and development of midge larvae showed similar trends among cover material treatments. Toxicity of leachates was more strongly correlated with water metal concentrations than with accumulated metals, suggesting that not all accumulated metals exerted toxic action. Significant adverse effects on invertebrates occurred in this study at metal concentrations comparable to those measured in the Big River system and in seepage from tailings piles.

The benefits of revegetation of the large tailings piles in the Old Lead Belt probably outweigh the adverse effects of cover materials on leachate formation. However, the processes observed in this study probably also act on tailings already eroded into stream and riparian habitats, posing a long-term threat of metal toxicity to aquatic biota and human consumers of contaminated fish. -- J.M. Besser.

Chupp, N.R. and P.D. Dalke. 1964. Waterfowl mortality in the Coeur d'Alene River Valley. J. Wildl. Manage. 28:692-702.

Waterfowl mortality in the Coeur d'Alene River Valley has aroused public concern since the early 1900's. An investigation and evaluation of the valley as waterfowl habitat was begun in 1954. Information from this and subsequent studies leaves little doubt that contamination of the Coeur d'Alene mining area is the prime cause of the bird losses. Analyses of numerous soil, plant, and waterfowl specimens collected in the valley showed abnormally high concentrations of lead, zinc, and copper. The toxic effects of the assimilated mine wastes, coupled with environmental stress in the winter and early spring, are apparently sufficient to produce the mortalities noted. Management considerations associated with alleviating the problem of bird losses in the Coeur d'Alene River Valley are discussed briefly. -- Authors' Abstract.

Coburn, D.R., D.W. Metzler, and R. Treichler. 1951. A study of absorption and retention of lead in wild waterfowl in relation to clinical evidence of lead poisoning. J. Wildl. Manage. 15:186-192.

The critical daily dosage level was found to be between 6 and 8 mg./kg. The avg. survival time for birds dosed at a level of 12 mg./kg. was 3.5 days less than for birds receiving lead at the 8 mg./kg. level, but there was no significant difference in the deposition of lead in the tissues of the 2 groups. Lead metabolism studies for 3 consecutive periods showed comparable rates of retention for the 2 dosage levels, with no significant difference in lead retention. The rate of deposition of lead in the tissues, as indicated by metabolism tests, was found to be such that related clincal symptoms could be predicted. Any one of 3 units, skeleton, liver, or soft tissues might be satisfactory as field samples for the detm. of lead poisoning by chemical analysis. -- J.B. DeWitt.

Cook, R.S. and D.O. Trainer. 1966. Experimental lead poisoning of Canada geese. J. Wildl. Manage. 30:1-8.

Canada geese (Branta canadensis) were experimentally exposed to known amounts of lead. The course of the lead and of the disease in geese was followed, utilizing established laboratory procedures. Gross signs of lead poisoning first appeared 5-7 days following ingestion. The length of time until signs of disease or death occurred was related to the amount of lead ingested. Twenty-five or more pellets resulted in death within 10 days, while 10 or fewer pellets permitted survival as long as 72 days. Ingestion of large numbers of pellets resulted in a rapid increase of lead levels in the blood, acute poisoning, and early death. Ingestion of fewer pellets resulted in a slower increase of lead in the blood, chronic poisoning, and longer survival, with more "typical" lead poisoning signs and pathology. Lead pellets appeared to erode at a constant rate regardless of the number in the gizzard. The largest lead pellet volume (66 percent) was eroded within the first 3 days after exposure, and it took approximately 45 days for the remaining volume to disappear. Normal lead levels of blood for Canada geese were found to be 0.018-0.037 mg/100 g blood. The lead levels of blood of lead-poisoned geese reached a peak between the third and tenth day, and ranged from 0.320-1.680 mg/100 g. Internal lesions as well as histopathological changes are described. High lead levels in blood and liver tissue, typical signs, and pathological lesions were necessary to diagnose lead poisoning in geese. The possible significance and effect of lead poisoning on the fecundity of geese are discussed. — Authors' Abstract.

Czarnezki, J.M. 1985. Accumulation of lead in fish from Missouri streams impacted by lead mining. Bull. Environ. Contam. Toxicol. 34:736-745.

Fish samples were taken from three areas impacted by lead mining: the Big River in the Old Lead Belt, streams in the New Lead Belt, and streams in the Tri-State Mining District. It was found that the Old Lead Belt area had the highest concentrations of lead in fish, with the golden redhorse having the highest (1.30 ppm). The World Health Organization's maximum safe level is 0.3 ppm in tissue for human consumption. Both the New Lead Belt and the Tri-State Mining District exhibited lower concentrations than the Big River area (highest concentration: 0.21 ppm and 0.49 ppm) and were not much different than the controls. -- D.M. Kania.

Davies, P.H. and W.H. Everhart. 1973. Effects of chemical variations in aquatic environments: Volume III, lead toxicity to rainbow trout and testing application factor concept. 80 pp.

Four chronic bioassays were conducted to determine the toxicity of lead to rainbow trout. Results obtained from acute and chronic bioassays in hard water (alkalinity 243.1 mg/liter) and soft water (alkalinity 26.4 mg/liter) were used to test the application factor approach as related to different water qualities. The toxicity of lead to rainbow trout in hard water was determined on a total and dissolved lead basis. The 96-hr TL_{50} and "MATC" on a total lead basis were 471 mg/liter and 0.12 to 0.36 mg/liter respectively, which yielded an application factor of .0002 to .0008. Analysis of the free or dissolved lead gave a 96-hr TL_{50} of 1.38 mg/liter and a "MATC" of 0.018 to 0.032 mg/liter, resulting in an application factor of .0130 to .0232. Total and free lead were considered to be the same in soft water. The 18-day TL_{50} and "MATC" obtained from the soft water bioassays were 140 micrograms/liter and 6.0 to 11.9 micrograms/liter lead respectively. Computations using the TL_{50} and "MATC" values gave a soft water application factor of .0429 to .0850. The maximum acceptable toxicant concentration ("MATC") was determined in both hard and soft water bioassays on the occurrence of abnormal black tails caused by chronic lead exposure. The application factor approach as related to different water qualities was found to be very promising when lead analysis was limited to the free or dissolved metal and failed when total hard water lead concentrations were used. — Authors' Abstract.

Elliott, L.E. 1982. Impacts of tailings from abandoned lead mines on the water quality and sediments of Flat River Creek and Big River in southeastern Missouri. M.S. Thesis, Univ. Mo. - Rolla.

Significant accumulations of century old lead mining wastes now exist as large tailings or chat piles in the Old Lead Belt of Southeastern Missouri. This material has been found to contribute to heavy metal contamination of the sediments of receiving streams in the area.

The National Tailings Pile was characterized for its heavy metal (Pb, Zn, Cd, and Cu) concentrations. Average values of each metal from the tailings pile and from severe erosion areas on the north and east sides of the pile were determined. For the main pile, lead averaged 3508 ppm, zinc 457 ppm, cadmium 7.2 ppm, and copper 183 ppm. The averages found in the north erosion area were: lead 2510 ppm, zinc 112 ppm, cadmium 4.9 ppm, and copper 61 ppm. In the east erosion area, these metals were found to average; lead 6894 ppm, zinc 295 ppm, cadmium 6.4 ppm, and copper 196 ppm.

Material from the National Tailings Pile was found to have been carried into Flat River Creek, and subsequently Big River, to become part of the stream sediment. Peak values for each of the metals in the sediment material downstream of the pile were: lead 7221 ppm, zinc 4875 ppm, cadmium 89 ppm, and copper 356 ppm.

The water quality parameters of Flat River Creek and Big River examined were: turbidity, pH, total alkalinity, total hardness, total and dissolved solids, total lead, zinc, cadmium, and copper, dissolved oxygen, and chemical oxygen demand. It was found that runoff from the National Tailings Pile posed no obvious detrimental impact under low flow conditions in regard to these water quality parameters. -- L.E. Elliott.

Erickson, D.W. and J.S. Lindzey. 1983. Lead and cadmium in muskrat and cattail tissues. J. Wildl. Manage. 47:550-555.

A study in southeastern Pennsylvania was conducted to determine the concentrations of lead and cadmium in cattails, since they are an important food source for muskrats; and the relation to levels in muskrat livers and kidneys. Rootstocks were found to contain higher concentrations of lead than the foliage and stems. Cadmium concentrations varied considerably. It was concluded that lead in muskrats varies in relation to prevailing environmental exposure. Cadmium relationships were not apparent. Also, it was found that females contained higher levels of cadmium than males. It was pointed out that other factors also influence the concentrations. -- D.M. Kania.

Gale, N.L., E. Bolter, and B.G. Wixson. 1976. Investigation of Clearwater Lake as a potential sink for heavy metals from lead mining in southeastern Missouri. In: D. Hemphill (ed.) Proc. 10th Ann. Conf. on Trace Substances in Environ. Health, Univ. of Mo.-Columbia, p. 187.

The geomorphology of Southeast Missouri makes Clearwater Lake near Piedmont the recipient of most of the surface waters draining the Viburnum Trend, the world's largest lead mining district. One major research concern has been the possible accumulation of heavy metals in this lake from the combined drainage. Conventional dredging methods as well as hand collection devices used by research scuba divers were employed to collect sediment samples. These, together with selected samples of aquatic biota, were analyzed to evaluate the extent of trace metal accumulation after approximately 8 years of mining operation. Release of heavy metals from the mining district occurs primarily in the form of metal-rich solids from mine tailings and runoff from soils contaminated by mining and smelting activities.

Heavy metals may also be transported in dissolved form. Possible mechanisms of dissolution, exchange and eventual transport of heavy metals from industrial sources are strongly influenced by humic acids from detritus and other organic constituents of living components of the environment. This biological activity will increase the dissolution of heavy metals solids, and also affect the geochemical mobility of metals through complexing and chelation.

In Clearwater Lake, lead concentrations in sediment ranged from less than 3 ppm at the points of stream entry to concentrations in excess of 60 ppm in deep quiescent water adjacent to the dam. Zinc and copper concentrations followed a similar trend, ranging from 10-84 ppm and 5-30 ppm respectively. Cadmium concentrations reached detectable levels (0.3 -0.5 ppm) only in samples collected near the dam.

Total body Pb content of bluegills, bass, goggle-eyes, catfish, and minnows collected in the lake ranged from undetectable levels to 14 ppm. The mucous membranes of skin and gills showed a particular affinity for heavy metals. Forage lead concentration in skin and scales ranged from undetectable levels in catfish to 21 ppm in bluegills. Gills from a variety of fish demonstrated Pb content of 5 - 18 ppm. Catfish gills were generally found to contain less Pb than those of bluegills. Freshwater mussels had total body Pb concentrations of 25-30 ppm, most of which was located in the shells. Soft internal tissues (muscle, heart, kidneys, gastrointestinal organs, and reproductive organs) did not have detectable quantities. These data allow some interesting comparisons with similar data collected from areas of much higher heavy metal concentrations in the mining district. — Authors' Abstract.

Gale, N.L., B.G. Wixson, M.G. Hardie, and J.C. Jennett. 1973. Aquatic organisms and heavy metals in Missouri's New Lead Belt. Water Resources Bulletin. 9:673-688.

The New Lead Belt of southeastern Missouri has recently become the largest lead producing region of the world. The impact of this rapid development on the previously rural and undeveloped region of the Missouri Ozarks is the subject of a continuing interdisciplinary study. Since the industrial development began, there have been a number of nuisance biological blooms in several of the small streams receiving effluent from the mines and mills. The major constituents of the problem algal growths were identified and found to include: Cladophora, Oscillatoria, Mougeotia, Zygnema, Spirogyra, Cymbella, and a variety of other stalked and non-stalked diatoms. Secondary blooms of Sphaerotilus were observed to reach problem proportions in some streams, particularly in the autumn. Finely ground rock flour and mineral particles escaping from tailings dams were found to be trapped by the stream vegetation. Concentrations of lead, zinc, copper, and manganese in the algal and bacterial mats were found to be inversely related to distance downstream from the tailings dams. Consumer organisms, including crayfish, snails, aquatic insects, tadpoles, minnows, and larger sunfish were analyzed to determine the extent of dissemination and concentration of the heavy metals through food chains. Preliminary results indicated significant concentrations of heavy metals in those consumer organisms studied, though in at least one problem stream the normal consumer organisms mentioned were markedly reduced in numbers. (KEY TERMS: New Lead Belt; Missouri; heavy metals; food chains; algal and bacterial mats). - Authors' Abstract.

George, L.C. 1983. Bureau of Mines, Overview Status Report. 4 pp.

Due to the rupture of a dam at Desloge, Missouri, and the subsequent washout of tailings into the Big River, many agencies got involved. Many proposals were recommended by various agencies, but either they did not get off the ground or the appropriate funding was not available. However, the Bureau of Mines, with the cooperation of other agencies, did a study on the tailings in 1981. Recommendations included vegetating the tailings to stabilize them, utilizing the tailings as construction material, and removing the tailings. Although the waters of the Big River are well within the established drinking water limits, the lead contamination is adversely affecting benthic fish. Vegetative stabilization was planned in 1981, but was cancelled. -- D. M. Kania.

Great Lakes Science Advisory Board. Report of the Aquatic Ecosystem Objectives Committee on Lead. (Unpublished) pp. 63-102.

Anthropogenic lead enters the Great Lakes via air and water, primarily as a result of its use in gasoline. Inorganic lead concentrations in excess of 1,000 - 10,000 micrograms/L quickly react with complexing materials in lake water and precipitate to the sediments. Particulate lead is not available to predatory fish through uptake across the gills, but there are data to suggest it is available to filter-feeding zooplankton, herbivorous fish, and fish that sift bottom mud for food organisms. Non-complexed lead at concentrations <1,000 micrograms/L is readily taken up by aquatic biota; however, since it is also available for adsorption to particulates, it should quickly disappear. Consequently, aquatic biota should be exposed to significant concentrations of non-complexed lead only near mixing zones of municipal and industrial effluents and river mouths. Bottom-feeding and herbivorous fish and filter-feeding zooplankton would also receive significant exposures anywhere that lead-contaminated particulates or sediments drift. The continual movement of fine-grained sediments in the Great Lakes will therefore cause widespread low-level contamination of these organisms. Further lead contamination may be caused by biological and chemical methylation processes in sediments; alkyl lead compounds have been observed in Great Lakes fishes. Other sources of organic lead in fish could be industrial wastes and spillage and evaporation of leaded gasoline. The lipophilic organo-lead compounds will behave differently from inorganic lead and will tend to accumulate easily and quickly in biological tissues.

Impacts of lead will be associated with point sources where aquatic biota respond to free lead in water, and in areas where contaminated sediments settle. The overall impact on aquatic biota is difficult to assess, but it will probably be greatest in long-lived organisms that are non-migratory and live near high-level point sources, since they will acquire a high lifetime exposure. Sensitive zooplankton and phytoplankton may be severely affected by drift through mixing zones, but presumably large population sizes would allow recolonization of affected water as it mixes with clean water. Adverse impacts are best documented for wildfowl populations that exhibit high mortality rates due to ingestion of spent lead shot. Lead contamination of drinking water is probably not a problem, based on existing surveillance data. However, since these data are generally collected offshore, there may be unknown instances of contamination of inshore intakes.

Inorganic lead contamination of fish as human food does not seem to be a problem, since total lead levels in wild fish or in fish exposed to high inorganic lead concentrations in the lab do not exceed previously published food guidelines. However, these guidelines have been recently withdrawn and are under review. — Author's Abstract.

Grue, C.E., T.J. O'Shea, and D.J. Hoffman. 1984. Lead exposure and reproduction in highway-nestling barn swallows. Condor. 86:383-389.

Lead concentrations in the carcasses and stomach contents of adult and nestling Barn Swallows (Hirundo rustica) collected within the right-of-way of a major Maryland highway were greater than those found in Barn Swallows nesting within a rural area. Lead concentrations in the feathers of adults from the highway colony were also greater than those of rural adults, but concentrations in the feathers of nestlings from the two locations were similar. Activity of delta-aminolevulinic acid dehydratase in red blood cells was lower in highway-nesting adults and their young than in their rural counterparts, although hemoglobin concentrations and hematocrits did not differ. The number of eggs, nestlings, and body weights of the latter at 16-18 days of age were similar in the two colonies, as were body weights of adults from the two areas. These results suggest that contamination of roadside habitat by lead from automotive emmissions does not pose a serious hazard to birds that are aerial feeders. — Authors' Abstract.

Hassett, J.J. 1974. Capacity of selected Illinois soils to remove lead from aqueous solution. Comm. in Soil Science and Plant Analysis. 5:499-505.

Lead is being added to the environment in automotive exhausts and as an industrial pollutant. To understand its fate in the environment, it is necessary that factors affecting the capacity of soils to sorb Pb be determined.

The capacity of soils to sorb Pb from aqueous solutions was measured for selected Illinois soils via column leaching experiments and adsorption isotherms. A regression equation was determined that predicted the capacity of soil to sorb Pb based on its C.E.C., pH and soluble P level. Results of the regression analysis indicated that soil properties associated with increasing C.E.C., i.e. higher organic matter content, high surface area, and high clay content, have a greater effect on Pb sorption than soil pH, and that soil pH has a greater effect than soluble P. — J.J. Hassett.

Hassett, J.J. 1976. Determination of lead sorption capacities of selected Illinois soils using titration curves. Comm. in Soil Science and Plant Analysis. 7:189-195.

The capacity of a soil to sorb or bind Pb^{+2} may be determined by titrating the soil with a $PbCl_2$ solution. The addition of Pb to the soil results in a shift in pH. The sorption capacity corresponds to the point of maximum curvature in the titration curve. Sorption capacities obtained in this manner are highly correlated with plant uptake. -- J.J. Hassett.

Hassett, J.J. and J.E. Miller. 1977. Uptake of lead by corn from roadside soil samples. Comm. in Soil Science and Plant Analysis. 8:49-55.

The uptake of Pb by young, greenhouse grown corn plants from roadside soil was found to be not only dependent upon the total amount of Pb in the soil, but also upon the amount of Pb in the soil relative to the soils capacity to sorb Pb. This is in agreement with the uptake of Pb by corn grown on soils amended with $PbCl_2$, although plant accumulation of Pb from roadside soils was much less than from $PbCl_2$ amended soils at comparable Pb concentrations. The use of crushed limestone as a road building material which results in high soil pH values next to the roadside is probably responsible for the reduced plant availability of Pb in the roadside soils. — Authors' Abstract.

Hassett, J.J., J.E. Miller, and D.E. Koeppe. 1976. Interaction of lead and cadmium on maize root growth and uptake of lead and cadmium by roots. Environ. Pollut. 11:297-302.

Radicle elongation of soil-grown maize seedlings was depressed by concentrations of 25 micrograms Cd/g of soil or 250 micrograms Pb/g of soil when the metals were added singly. When Pb and Cd were added in combination inhibition of radicle elongation occurred at significantly lower concentrations. The effect of the metals when added in combination was greater than the sum of effects when the metals were added singly, thus strongly suggesting a synergistic interaction. The effect was partially attributed to elevated accumulation of the metals in combination treatments. — Authors' Abstract.

Hoffman, D.J., J.C. Franson, O.H. Pattee, C.M. Bunck, and A. Anderson. 1985. Survival, growth, and accumulation of ingested lead in nestling American kestrels (Falco sparverius). Arch. Environ. Contam. Toxicol. 14:89-94.

One-day old American Kestrel (Falco sparverius) nestlings were dosed orally daily with 5 micrograms/L of corn oil (controls), 25 mg/kg, 125 mg/kg, or 625 mg/kg of metallic lead in corn oil through day 10. Forty percent of the nestlings given 625 mg/kg died after six days. Growth rates became significantly different from controls in the

625 mg/kg group by day 3 and in the 125 mg/kg group by day 4. Crown-rump lengths and brain weights were significantly lower in both treatment groups. Liver and kidney weights were lower in the 625 mg/kg groups. Skeletal examination and measurement of alizarin red-S stained nestlings revealed reduced growth for the humerus, radius-ulna, femur, and tibiotarsus in the 125 mg/kg and 625 mg/kg groups. Skeletons were otherwise normal in appearance. Greater than 2 ppm (wet weight) lead in the liver or 6 ppm in the kidney was associated with suppressed growth, while more than 5 ppm in the liver and 15 ppm in the kidney occurred in survivors in the 625 mg/kg group. The order of accumulation of lead in tissues at the end of 10 days was kidney > liver > brain. These findings suggest that altricial nestlings may be considerably more sensitive to lead exposure than adults and also more sensitive than hatchlings of many precocial species. — Authors' Abstract.

Kendall, R.J. and P.F. Scanlon. 1982a. Tissue lead concentrations and blood characteristics of rock doves from an urban setting in Virginia. Arch. Environ. Contam. Toxicol. 11:265-268.

Rock doves (Columba livia) live-trapped in Blacksburg, Va. had the following blood characteristics measured: Delta-aminolevulinic acid dehydratase (ALAD) activity, packed cell volume (PCV), and hemoglobin (Hb). Lead concentrations were measured in livers and femurs. Concentrations of lead in femurs were indicative of chronic exposure to lead in many individuals. A linear relationship was noted between ALAD activity and liver lead concentrations with ALAD decreasing with increased lead concentrations. — Authors' Abstract.

Kendall, R.J. and P.F. Scanlon. 1982b. Tissue lead concentrations and blood characteristics of mourning doves from southwestern Virginia. Arch. Environ. Contam. Toxicol. 11:269-272.

Studies were conducted on the feasibility of sampling the blood from live mourning doves (Zenaida macroura) as a technique for evaluating lead exposure in this species. Measurements of the blood enzyme, delta-aminolevulinic acid dehydratase (ALAD), were essentially the same in blood from the brachial vein or trunk blood. The ALAD activity decreased as liver lead concentration increased in mourning doves. Mourning doves that ingested lead shot had elevated lead concentrations in their femur bones and livers as compared to other doves which had not recently ingested lead shot. -- Authors' Abstract.

Knowlton, M.F., T.P. Boyle, and J.R. Jones. 1982. Uptake of lead from aquatic sediment by submersed macrophytes and crayfish. Arch. Environ. Contam. Toxicol. 12:535-541.

Uptake of lead (Pb) by submersed aquatic macrophytes and crayfish exposed to artificially contaminated pond sediment was measured under laboratory conditions. Macrophytes accumulated Pb in root tissue and foliage. Internal transport of Pb by plants was not detected. Senescent macrophytes accumulated more than live plants. Crayfish exposed to contaminated sediment accumulated Pb principally through adsorption to the exoskeleton and lost Pb through molting, although internal uptake and elimination without molting was measurable. Exposure to Pb leached from sediment, surface to weight ratios, and frequency of molting seem to influence Pb uptake by crayfish. -- Authors' Abstract.

Lu, P.Y., R.L. Metcalf, R. Furman, R. Vogel, J. Hassett. 1975. Model ecosystem studies of lead and cadmium and of urban sewage sludge containing these elements. J. Environ. Qual. 4:505-509.

The environmental fate and effects of cadmium and lead were studied in a laboratory model ecosystem with a terrestrial/aquatic interface, using silica sand, Bloomfield soil (sandy loam), and Drummer soil (silty clay loam) as substrates. Applications were made directly to the substrates as lead and cadmium chloride and as sewage sludge as a source of heavy metals. The mobilization and incorporation of cadmium and lead into food chain organisms were proportional to sorption capacity of the substrate and were highest in silica sand and lowest in Drummer soil. Following the application of sewage sludge there was clear cut mobilization and transfer of cadmium, copper, lead, and zinc into food chains, algae (Oedogonium cardiacum), daphnia (Daphnia magna), mosquito larvae (Culex pipiens quinquefasciatus), snail (Physa), and fish (Gambusia affinis). Cadmium exerted a particularly adverse affect on the various organisms in the model ecosystem and its presence in relatively high levels in sewage sludge could become a limiting factor in its use on soils and for crop production. -- Authors' Abstract.

Miller, J.E., J.J. Hassett, and D.E. Koeppe. 1977. Interactions of lead and cadmium on metal uptake and growth of corn plants. J. Environ. Qual. 6:18-20.

Short term plant accumulation and growth effects of Pb and Cd added to soil separately and in combination were investigated with corn (Zea mays L., Wf9 X M14) grown in a loamy sand under greenhouse conditions. A tendency for soil Pb to increase both the plant Cd concentration and the total Cd uptake of the corn shoots was observed. Conversely, soil Cd reduced the total Pb uptake and in some cases the Pb concentration in the corn shoots. Both Pb (125 and 250 micrograms/g soil) and Cd (2.5 and 5 micrograms/g soil) reduced the vegetative growth of the corn shoots, and a positive interaction of the two metals on growth was noted. — Authors' Abstract.

Moore, J.W. and S. Ramamoorthy. 1979. Heavy metals in natural waters. Chapter 6. Lead. pp. 100-124.

Chapter six of this book deals with lead. Lead has been used mainly in storage batteries, metal products, chemicals, pigments, and various other products. Discharges of lead include emissions into the atmosphere, either naturally as in wind-blown dust, or through automobile exhaust and metal production. Lead in aquatic systems either binds to inorganic and organic ligands and/or particulates, and is easily transported through natural waters. Sediment accumulation is correlated to organic content and grain size. Greater than 500 ppm lead have been produced from the discharge of liquid mine wastes. High residue concentrations are also common for attached plants inhabiting polluted waters. Good biomonitors of contamination include freshwater species of <u>Elodea</u>, <u>Cladophora</u>, and <u>Myriophyllum</u>. Also, invertebrates and fish are prone to lead contamination. Humans are susceptible to lead through the respiratory tract, with urban airborne particulates representing the major source. — D.M. Kania.

Morgan, G.W., F.W. Edens, P. Thaxton, and C.R. Parkhurst. 1975. Toxicity of dietary lead in Japanese quail. Poultry Science. 54:1636-1642.

The toxicity of dietary lead in Japanese quail was investigated. The data indicated that dietary lead, in the form of lead acetate, was toxic to young quail at the level of 500 ppm and this toxicity was evidenced by an inhibition of normal growth and by anemia. The anemic state in the lead toxic quail was more readily detected by reduced blood hemoglobin concentrations than by packed cell volumes. In addition, the data suggested that lead interfered with normal sexual development in the males. Lead at levels as high as 1000 ppm did not prevent normal primary antibody responses to sheep erythrocytes. — Authors' Abstract.

Niethammer, K.R., R.D. Atkinson, T.S. Baskett, and F.B. Samson. 1985. Metals in riparian wildlife of the lead mining district of southeastern Missouri. Arch. Environ. Contam. Toxicol. 14:213-223.

Five species of riparian vertebrates (425 individuals) primarily representing upper trophic levels were collected from the Big River and Black River drainages in two lead mining districts of southeastern Missouri, 1981-82. Big River is subject to metal pollution via erosion and seepage from large tailings piles from inactive lead mines. Black

River drains part of a currently mined area. Bullfrogs (Rana catesbeiana), muskrats (Ondatra zibethicus), and green-backed herons (Butorides striatus) collected downstream from the source of metal contamination to Big River had significantly (ANOVA, $P<0.05$) higher lead and cadmium levels than specimens collected at either an uncontaminated upstream site or on Black River. Northern water snakes (Nerodia sipedon) had elevated lead levels below the tailings source, but did not seem to accumulate cadmium. Levels of lead, cadmium, or zinc in northern rough-winged swallows (Stelgidopteryx serripennis) were not related to collecting locality. Carcasses of ten bank swallows (Riparia riparia) collected from a colony nesting in a tailings pile along the Big River had lead concentrations of 2.0-39 ppm wet weight. Differences between zinc concentrations in vertebrates collected from contaminated and uncontaminated sites were less apparent than differences in lead and cadmium. There was little relationship between metal concentrations in the animals studied and their trophic levels. Bullfrogs are the most promising species examined for monitoring environmental levels of lead, cadmium, and zinc. Downstream from the source of tailings, bullfrogs had markedly higher levels of these metals in most of their tissues. The species is also widely distributed in North America, easily caught, and relatively sedentary. — Authors' Abstract.

Niethammer, K.R., M.S. Kaiser, R.D. Atkinson, and T.S. Baskett. 1983. Foods of the green-backed heron in the eastern Missouri Ozarks. Biological Sciences. pp. 117-127.

Analysis of upper digestive tracts of 107 green-backed herons (Butorides striatus) collected between 15 May 1981 and 15 September 1982 in the eastern Missouri Ozarks provided information on foods of this species in riverine and lacustrine habitats. Immature green-backed herons took more invertebrates (crayfish and insects), fewer fishes and smaller fishes than adult males, whereas the diet of adult females was intermediate. For example, fishes made up 70, 78, and 93% of diets of immatures, adult females and adult males, respectively, based on weight of prey. Insects and crustaceans constituted 28, 13, and 6%, respectively, of diets of immatures, adult females and adult males. A comparison of our data derived from digestive tracts with those obtained from an observational study in similar habitats of the same region indicated that observational studies may underestimate the number of small prey (e.g., insects) in the diet. Key Words: Green-backed heron, food habits, Missouri. -- Authors' Abstract.

Nriagu, J.O. (ed.) 1978. The biogeochemistry of lead in the environment, Part A. Elsevier/North Holland, N.Y., pp. 54-63.

Chapter 2 of this book concentrates on lead in sediments, both lake sediments and river sediments. The average lead content of an unpolluted lake sediment has been estimated at 16 ppm. The accumulation of lead comes from such sources as inputs from stream sediments and waters, groundwater, erosion of lake banks, fallout of windborne materials, and discharges of industrial and domestic effluents. The average lead value for riverine sediments with pollution is estimated to be 98 ppm. The concentration of lead in various soils, such as cosmos, meteorites and lunar samples, and major rock types is also dealt with in this chapter. — D.M. Kania.

Schmitt, C.J. 1985. Chemical characterization and biological activity of metals in leachates from lead mine tailings. U.S. Fish and Wildlife Service, Columbia National Fisheries Research Laboratory, Columbia, Missouri.

Raised bed test plots containing 15 - 20 cm of mine tailings from the old Lead Belt in southeastern Missouri were used in studying the effects of cover materials on leaching of Pb, Cd, Zn, and other chemical constituents from the tailings. The following cover materials, chosen to simulate the effects of vegetative stabilization of tailings piles, were studied: anaerobically digested sewage sludge ("S"), silver maple leaves ("L"), sod ("G"), fertilizer/seed mixture ("F"), and untreated ("U"). The plots were situated outdoors, and the rainfall leachates collected in vinyl receiving pools.

Comparison of filtrable metal concentrations in leachates utilized the Bonferroni multiple comparison method ($p<0.05$) applied to ranked data. The following effects were observed during the first study season: Pb - L > U > F; Cd - S - L > U; Zn - S > U > F. During the second season, leaching of Pb and Zn from the leaf covered plot was greater than from the control plot.

Concentrations of Pb, Cd, Zn, and other metals were much lower in the receiving pool waters than in the initial leachates. Column studies showed the effects of the leaf and fertilizer treatments to be greatly reduced by percolation of the leachate through deeper layers of tailings.

Modeling of the data using the REDEQL.EPAK computer program indicated that the leachates were supersaturated with respect to HCO_3, $CaCO_3$, and $ZnSiO_3$. Pb was predicted to be present primarily as $PbCO_3$ ion pair. Significant concentrations of "free" (aquated) Cd and Zn were predicted.

Filterable portions of Pb, Cd, and Zn were found to be completely dialyzable in non-turbid effluent samples, while non-dialyzable filtrable Pb was present in turbid effluent samples. Significant non-dialyzable fractions of all three ions were found in the filtrable portions of receiving pool waters.

Chelex 100 non-labile fractions of Pb were found present in leaf covered plot effluent and receiving pool water samples. Non-dialyzable species in these leachates were found to concentrate considerable amounts of Pb. Experiments with XAD 2 resin indicated these species to be non-polar. — C.J. Schmitt.

Schmitt, C.J., F.J. Dwyer, and S.E. Finger. 1984. Bioavailability of Pb and Zn from mine tailings as indicated by erythrocyte delta-aminolevulinic acid dehydratase (ALA-D) activity in suckers (Pisces: Catostomidae). Can. J. Fish. Aquat. Sci. 41:1030-1040.

The activity of the erythrocyte enzyme delta-aminolevulinic acid dehydratase (ALA-D) was measured in 35 catostomids (black redhorse, Moxostoma duquesnei; golden redhorse, M. erythrurum; northern hogsucker, Hypentelium nigricans) collected from three sites on a stream contaminated with Pb-, Cd-, and Zn-rich mine tailings and from an uncontaminated site upstream. Enzyme activity was expressed in terms of hemoglobin (Hb), DNA, and protein concentrations; these variables can be determined in the laboratory on once-frozen blood samples. Concentrations of Pb and Zn in blood and of Pb in edible tissues were significantly higher, and ALA-D activity was significantly lower, at all three contaminated sites than upstream. At the most contaminated site, ALA-D activity was 62-67% lower than upstream. Lead concentrations in the edible tissues and in blood were positively correlated ($r = 0.80$), whereas ALA-D activity was negatively correlated with Pb in blood ($r = -0.70$) and in edible tissues ($r = -0.59$). Five statistically significant relations between Pb and Zn in blood and ALA-D activity were determined. The two models that explained the highest percentage (>74%) of the total variance also included factors related to Hb concentration. All five significant models included negative coefficients for variables that represented Pb in blood and positive coefficients for Zn in blood. The ALA-D assay with results standardized to Hb concentration represents an expedient alternative to the more traditional hematocrit standardization, and the measurement of ALA-D activity by this method can be used to document exposure of fish to environmental Pb. — Authors' Abstract.

Schmitt, C.J. and S.E. Finger. 1982. The dynamics of metals from past and present mining activities in the Big and Black River watersheds, southeastern Missouri. Report to the U.S. Army Corps of Engineers, St. Louis District. U.S. Fish and Wildlife Service, Columbia National Fisheries Research Laboratory, Columbia, Missouri. 153 pp.

Lead, cadmium, and zinc were found in elevated levels in all forms examined in this study: algae, rooted plants, crayfish, mussels, and fish; so that the authors have no doubt as to the bioavailability of lead in the mining area of the Old Lead Belt. It was found that lead from the tailings is transported in the solid phase, and concentrations in the suspended load increase with water flow. Only barium appeared to be transported in a liquid phase to any extent. Both lead and cadmium were found to remain in an available form. Concentrations of metals in Clearwater Lake were all low levels and posed no serious threat. However, the downstream sections of the Big River showed the highest quantities of trace metals, with those accumulations in fish exceeding the recommended levels for human consumption. -- D.M. Kania.

Schmitt, C.J., S.E. Finger, T.W. May, and M.S. Kaiser. 1984. The availability of particulate lead and cadmium from mine tailings to the pocketbook mussel. Annual winter meeting, American Society of Limnology and Oceanography and American Geophysical Union. San Francisco, California. December 6.

The Big River, a hard-water stream in southeastern Missouri, has been heavily contaminated by mine tailing rich in Pb and Cd. We measured concentrations and estimated the availability of Pb and Cd in tailings and in streambed sediments from one site above (11 km) and two below (0.5 and 93 km) a source of tailings to the stream by collecting them in five fractions: exchangeable, carbonate-bound, oxide-bound, organic-bound, and residual. Pb and Cd concentrations were also measured every 2 wk for 8 wk in pocketbook mussels collected from an uncontaminated stream and caged at the three Big River sites.

Both Pb and Cd originally occurred as insoluble sulfides; nevertheless, relatively little Pb remained in the residual fraction, even in tailings and 0.5 km downstream. Conversely, > 50% of both Pb and Cd occurred in the carbonate-bound and oxide-bound fractions. Relatively small percentages of Pb and Cd were found in the exchangeable and organic-bound fractions at all sites. Mussels at both contaminated sites rapidly accumulated Pb and Cd in their soft tissues; those placed upstream did not. Examination of the gut contents of indigenous pocketbook mussels from the Big River revealed a much finer particle-size distribution than that of surficial stream sediments at capture sites. Correlation and regression analyses were used to investigate the relations between particle size distributions, relative extractability of Pb and Cd from sediments, and the observed uptake of Pb and Cd by mussels. -- Authors' Abstract.

Spruill, T.B. 1985. Assessment of water resources in lead-zinc mined areas in Cherokee County, Kansas, and adjacent areas. U.S. Geological Survey. Open-file report. pp. 84-439.

A study was conducted to evaluate water-resources problems related to abandoned lead and zinc mines in Cherokee County, Kansas, and adjacent areas in Missouri and Oklahoma. Past mining activities have caused changes in the hydrogeology of the area. Lead and zinc mining has caused discontinuities and perforations in the confining shale west of the Pennsylvanian-Mississippian geologic contact (referred to as the western area), which have created artificial ground-water recharge and discharge areas. Recharge to the shallow aquifer (rocks of Mississippian age) through collapses, shafts, and drill holes in the shales has caused the formation of a ground-water "mound" in the vicinity of the Picher Field in Kansas and Oklahoma. Discharge of mine-contaminated ground water to Tar Creek occurs in Oklahoma from drill holes and shafts where the potentiometric surface of the shallow aquifer is above the land surface. Mining of ore in the shallow aquifer has resulted in extensive fracturing and removal of material, which has created highly transmissive zones and voids and increased ground-water storage properties of the aquifer. In the area east of the Pennsylvanian-Mississippian geologic contact (referred to as the eastern area), fractured rock and tailings on the land surface increased the amount of water available for infiltration to the shallow aquifer; in the western area, tailings on the impermeable shale created artificial, perched-aquifer systems that slowly drain to surface streams.

Pumping of the deep aquifer (rocks of Cambrian and Ordovician age) by towns and industries, which developed as a result of the mining industry, has resulted in a potential for downward movement of water from the shallow aquifer. The potential is greatest in Ottawa County, Oklahoma. Because of the large volume of water that may be transported from the shallow to the deep aquifer, open drill holes or casings present the greatest contamination hazard to water supplies in the deep aquifer.

Mining allowed oxidation of ore deposits which, on saturation with water, resulted in poor-quality water that generally contains large concentrations of sulfate and trace metals. Water from mines in the eastern area contained dissolved-solids concentrations of less than 500 mg/L (milligrams per liter), a median pH of 3.9, sulfate concentrations that ranged between 98 and 290 mg/L, and median concentrations for zinc of 37,600 micrograms/L (micrograms per liter), for lead of 240 micrograms/L, for cadmium of 180 micrograms/L, for iron of 70 micrograms/L, for manganese of 240 micrograms/L, and for silica of 15 mg/L. Water from mines in the western area contained dissolved-solids concentrations of generally more than 500 mg/L, a median pH of 6.8, sulfate concentrations that ranged between 170 and 2,150 mg/L, and median concentrations for zinc of 3,200 micrograms/L, for lead of 0 micrograms/L (minimum detection limit is 10 micrograms/L), for cadmium of 6 micrograms/L, for iron of 840 micrograms/L, for manganese of 440 micrograms/L, and for silica of 11 mg/L.

No conclusive evidence of lateral migration of water from the mines into the domestic well-water supplies in the shallow aquifer was found in the study area in Kansas. Analyses of water from public-supply wells tapping the deep aquifer did not indicate contamination with trace metals, although chemical analyses from four of six wells exhibited increasing trends through time in sulfate concentrations. These increases probably reflect localized leakage of water from the shallow aquifer along corroded or leaky well casings.

Effects of abandoned lead and zinc mines on tributaries of the Spring River in the eastern area are most severe in Short Creek. Compared with water samples from three other major streams in the eastern area, a sample collected from Short Creek, 2 miles west of Galena, Kansas, during August 1981, contained the largest concentrations of dissolved sulfate (240 mg/L), zinc (25,000 micrograms/L), cadmium (170 micrograms/L), manganese (1,700 micrograms/L), and the lowest pH (6.0). Concentrations of these constituents are due primarily to inflow of ground water from the breccia, mines, and to seepage from chat piles in the Short Creek basin. The largest concentrations of zinc and manganese in the Spring River during August 1981, were observed in analyses of samples collected below Short Creek. In the western area, drainage from tailings, which act as perched aquifers on the impervious Pennsylvanian shales, appeared to have little effect on water quality in Willow Creek during low-flow conditions but caused larger concentrations of dissolved zinc just after a wet period during June 1981. Drainage from tailings cause large concentrations of sulfate, zinc, and cadmium in Tar Creek in Kansas. Compared with four other major streams in the western area in Kansas, Tar Creek contained the largest low-flow concentrations of sulfate (910 mg/L), zinc (5,800 micrograms/L, and cadmium (40 micrograms/L).
— T.B. Spruill

Stone, C.L., M.R.S. Fox, A.L. Jones, and K.R. Mahaffey. 1977. Delta-aminolevulinic acid dehydratase - a sensitive indicator of lead exposure in Japanese quail. Poultry Science. 56:174-181.

Red blood cell delta-aminolevulinic acid dehydratase (RBC-ALAD) activity has proven to be a sensitive indicator of lead exposure in humans. The depressed enzyme activity and its negative correlation to blood lead concentrations are well-known effects of lead exposure in man. The sensitivity of RBC-ALAD activity in young Japanese quail exposed to low levels of lead as lead acetate was investigated. Two groups of nine birds each were fed purified diets containing either no added lead or 25 micrograms of lead per g. of diet. After 2 weeks, blood and tibial tissues were collected. There were no significant differences between controls and lead-fed birds, in body, kidney, duodenal, and tibial weights, or in hematocrit and hemoglobin concentrations. However, the renal, hepatic, duodenal, and tibial lead concentrations were significantly (P<0.001) greater in the lead-treated birds. The activity of RBC-ALAD in the group fed lead was 45% of that in the control group; these values were significantly different (P<0.001). RBC-ALAD activity expressed as the log base 10 showed significant (P<0.02) negative correlation with both hepatic and tibial lead. The study demonstrates that the activity of RBC-ALAD in the Japanese quail is a very sensitive indicator of lead exposure. — Authors' Abstract.

Walker, W.M., J.E. Miller, and J.J. Hassett. 1977. Effect of lead and cadmium upon the boron, copper, manganese, and zinc concentration of young corn plants. Commun. in Soil Science and Plant Analysis. 8:57-66

In a greenhouse experiment corn plants were harvested 24 and 31 days following emergence from pots containing Bloomfield loamy sand (Psammentic Haplaudalf). Soil P was 140 kg/ha, exchangeable K was 220 kg/ha, and soil pH was 6.0. The soil CEC was 2.3 meg/100g. Boron, Cu, Mn, and Zn were determined with emmission spectroscopy. Treatment combinations were a factorial arrangement of 0, 2.5, and 5 micrograms/g of Cd and 0, 125, and 250 micrograms/g of Pb.

Main effects of Cd and Pb significantly affected the B concentration of corn plants 24 days following emergence, and specific main effects (linear and/or quadratic) influenced the concentration of other nutrients.

At the later stage of development (31 days following emergence), neither Cd nor Pb affected B concentration in corn plants, and there was only one significant (a=0.05) main effect influencing the nutrient status of other micronutrients studied. However, several Cd-Pb interactions affected micronutrient concentration in corn plants. Our results suggest that the effect of Cd or Pb upon the nutritional status of corn depends upon stage development of the plant as well as the Cd or Pb rate. — Authors' Abstract.

Whelan, G.E. 1983. The distribution and accumulation of lead and cadmium within a lotic benthic community. M.S. Thesis, Univ. Mo.-Columbia.

Three points are emphasized in this study: "1) sediments have metal complexes that can be mobilized, taken up and accumulated by aquatic biota; 2) Pb and Cd can be toxic to aquatic life; and 3) chronic levels of Pb and Cd could potentially disrupt the functioning, production, and community structure of aquatic systems." It was found that the tailings inputs had elevated total sediment Pb and Cd concentrations, but more important than the concentrations for Pb was the sediment particle size. The finer particle sizes, due to their charged properties and increased surface area available for adsorption, were found to have elevated metal concentrations. Foods, such as detritus and algae, that invertebrates feed on acquired lead through adsorption. Detritus consumers showed the highest metal concentrations as they ingest the smaller, metal-enriched particles. Predators, piercers, and engulfers all showed elevated lead levels. Both particle size of sediments and food quality are important to metal accumulation in benthic invertebrates. -- D.M. Kania.

White, D.H. and E. Cromartie. 1985. Bird use and heavy metal accumulation in waterbirds at dredge disposal impoundments, Corpus Christi, Texas. Bull. Environ. Contam. Toxicol. 34:295-300.

The study was conducted to determine the extent to which aquatic birds use dredge-pits and to determine the accumulation of heavy metals within these birds. Most birds were found to use the area seasonally and nine species were present more than 20% of the time. Accumulation of metals in the sediment samples were: lead, 49.2 ppm; zinc 847.6 ppm; cadmium, 7.5 ppm; mercury, 0.5 ppm; and selenium, 2.3 ppm. The concentrations within the birds were less than the levels in the sediment and were also no higher than the birds from control sites, except for selenium, which may have an adverse affect on these birds. -- D.M. Kania.

Wixson, B.G. (ed.) 1977. The Missouri Lead Study, Volume 1. National Science Foundation, Washington, D.C. 543 pp.

Heavy metals such as lead, zinc, copper, silver, and cadmium were studied in this book because of their hazard to the environment. In Volume 1, lead levels in deer bone, thallium and the use of fruit flies as an environmental indicator, and other analytical procedures are discussed. Air quality studies were also reviewed, and divided into stationary sources and non-point sources, such as trucking or railroad operation. The major source of heavy metal particulates was found to come from the non-point sources. Although the concentrations were low, they occasionally reached hazardous levels in short-term peaks. Soil content indicated that there may be a problem with heavy metal pollution. Furthermore, the physical-chemical parameters of water quality in the study areas are presented with emphasis on metals, overt and transport, trace organics, new waste treatment techniques, and a comparison between new modern mine-mill operations and techniques used 100 years ago. Biological effects of water quality are also examined. -- D.M. Kania.